SAMPLING DESIGN

for

TACOMA SMELTER PLUME SITE
PIERCE COUNTY "FOOTPRINT" STUDY

SOIL ARSENIC AND LEAD CONTAMINATION

TACOMA-PIERCE COUNTY HEALTH DEPARTMENT

for

WASHINGTON STATE DEPARTMENT OF ECOLOGY

March 2002

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1.0 Introduction

ASARCO operated a primary copper smelter, specializing in the toll smelting of complex (e.g., high-arsenic) ores, at Ruston, Washington for almost 100 years. That smelter, referred to as the Tacoma Smelter, closed in 1986. For many years, the Tacoma Smelter was the sole domestic source of arsenic for the U.S. market.

Since the early 1970s, many studies have been performed to evaluate contaminant emissions and environmental impacts from operations of the Tacoma Smelter. The smelter and surrounding areas were included as part of the Commencement Bay Superfund site. EPA issued a Record of Decision (ROD) for cleanup of the Ruston/North Tacoma operable unit of that Superfund site, consisting of mostly residential neighborhoods within approximately one mile of the former smelter site. ASARCO is currently performing remedial actions at properties in EPA's ROD site boundary, as well as at the former smelter site itself.

Contamination has been documented beyond the current EPA Superfund site boundary for Ruston/North Tacoma in a number of studies, both historic and recent. In 1998/1999, soil sampling and analysis conducted in connection with a proposed large-scale gravel mining project on Maury Island (King County) showed significant levels of arsenic and lead contamination at a distance of about 6 miles northeast and downwind from the Tacoma Smelter. At about the same time, soil sampling and analysis in University Place (Pierce County), about 6 miles southwest and downwind of the smelter, also showed significant arsenic and lead contamination. In response to this information, Ecology started investigations of what has come to be called the Tacoma Smelter Plume site under Washington's Model Toxics Control Act (MTCA).

Among other tasks for the initial Tacoma Smelter Plume site investigations, Ecology has supported several studies to better define the magnitude and extent of soil contamination. The

first three studies were performed in King County by Public Health - Seattle & King County (PHSKC), using Site Hazard Assessment grant funding from Ecology. Those studies included: 1) sampling in forested (undeveloped) areas over all of Vashon-Maury Island and along the King County mainland shoreline (see Glass 1999 and PHSKC and Glass 2000); 2) sampling in developed public child-use areas on Vashon-Maury Island, including schools and preschools, daycare centers, parks, camps, and beaches (see Glass 2000 and PHSKC and Glass 2001); and 3) sampling in relatively undisturbed, forested areas on mainland King County (see Glass 2001; data report in preparation). Ecology has now completed an amended Site Hazard Assessment (SHA) grant (No. G-0000263) with the Tacoma-Pierce County Health Department (TPCHD) to extend the initial assessment of the magnitude and extent of soil contamination related to Tacoma Smelter emissions through western Pierce County. Under this SHA grant scope of work, the initial Pierce County study is referred to as the "Footprint" study (subtask 7.2). A review of historic studies (subtask 7.1.2) is also included (see section 4.1 below).

A Footprint Study Sampling Design Work Group was convened including representatives of TPCHD and Ecology; Gregory L. Glass, an independent environmental consultant, also participated in all Work Group meetings and facilitated discussions of sampling design issues and options. The Work Group met through November and December 2001 in an intensive sample design process. Work Group members defined study objectives, compiled and evaluated information from historic studies, reviewed previous Tacoma Smelter Plume sampling designs, balanced decisions on various study design elements with project constraints, and through a consensus process developed the study design discussed in this memorandum.

2.0 Study Objectives

The overall objective for the Footprint Study is to provide a better understanding of the scope of Tacoma Smelter Plume Site contamination. Three specific study objectives have been identified:

- defining the regional-scale magnitude and extent of soil contamination in Pierce County
- completing sampling throughout western Pierce County to provide early, if imprecise and incomplete, indications of site boundaries
- identifying the likely contribution of the Tacoma Smelter as a source for soil arsenic and lead contamination

This regional-scale soil investigation, performed as part of the early Site Hazard Assessment phase of the cleanup process, is not intended to provide property-by-property results, detailed site boundaries, or a determination of natural background concentrations.

2.1 Magnitude and Extent of Contamination

The primary objective of the Pierce County Footprint Study is to better define the possible magnitude and extent of soil contamination from Tacoma Smelter emissions. Data on soil contamination by arsenic, lead, and occasionally other analyzed metals from previous studies, considered cumulatively, are no more than suggestive of the regional-scale contamination patterns in Pierce County downwind from the Tacoma Smelter. Information from the historic studies is limited by comparatively low sampling density, variations in the land use and development status of sampled properties, and the lack of consistent sampling and analysis protocols across studies.

In defining the magnitude of contamination, it is the objective of this study to characterize reasonable upper bound concentrations across the study area - that is, to define how large soil contaminant concentrations may get. Localized variability in soil contamination has been shown to be significant in previous Tacoma Smelter Plume Studies; such localized variability is expected to occur in Pierce County as well. Factors such as topography (elevation and slope), historical land cover and surface "roughness" that can affect deposition of airborne contaminants, and the degree of soil disturbance, among others, are all thought to contribute to the observed local variability in soil concentrations. Where practical, choices of sampling locations will reflect this bias or preference toward higher concentrations of smelter-related soil contamination. The most meaningful mapping of soil contamination at this early stage of site characterization is based on the highest potential concentrations to show where problems may be most severe.

To accomplish the primary study objective, soil samples will be collected over a large spatial area (almost 200 square miles) in western Pierce County and analyzed for arsenic and lead. The density of sampling is planned to support regional-scale mapping of contamination patterns. The proposed sampling densities are greater in areas closer to the Tacoma Smelter where the magnitude of soil contamination, and also local variability, are expected to be greater; sampling densities are comparatively lower at greater distances from the smelter, where the magnitude of soil contamination and local variability are expected to be lower. The proposed study design will greatly increase the level of information available within the study area, and data comparability will be enhanced through application of a systematic sampling approach and consistent analytical protocols.

The results of this study can be combined with data reported in the similar King County studies to provide a preliminary evaluation of the overall pattern of soil contamination from Tacoma Smelter emissions. Therefore, data comparability across studies is an important objective; a generally consistent study design has been adopted for the Footprint Study.

2.2 Initial Boundary Survey

Neither the King County studies nor the Pierce County Footprint Study (all developed as

part of the early Site Hazard Assessment phase of the MTCA cleanup process) are designed to provide a precise determination of the spatial boundaries at which Ecology's MTCA soil cleanup levels are exceeded. Such boundaries are very likely to be determined by soil arsenic concentrations. Arsenic is the best indicator contaminant of Tacoma Smelter impacts; the MTCA Method A soil cleanup level for arsenic (unrestricted land use) is 20 parts per million [ppm]. The Work Group decided, however, that a second objective of the Footprint Study should be inclusion of areas up to the northern and western boundaries of the western part of Pierce County to complete at least an initial survey of soil arsenic and lead levels in western Pierce County. Sampling in these areas, some of which are not identified by wind roses as dominant downwind directions from the Tacoma Smelter, is anticipated to provide some information relevant to defining partial boundaries for the Tacoma Smelter Plume Site. It will also help determine whether soil contamination from the smelter could be present in adjoining counties. The density of sampling in areas near the western and northern county boundaries will be low because of overall project resource constraints. As a result, sampling in those areas represents at best a pilot study and not a detailed boundary study.[1] The southern and eastern limits of sampling for the Footprint Study were selected to include a large area in the general south/southwest downwind direction, consistent with the results from historic studies, but without a specific objective of defining boundaries for the Tacoma Smelter Plume site (see Study Area Definition in section 4.0 below).

2.3 Tracer Element Analyses for Source Identification

Earlier Tacoma Smelter Plume studies on Vashon-Maury Island and the King County mainland included analysis of selected samples for additional tracer elements to confirm the source(s) of arsenic and lead contamination (report on tracer results in preparation). The Work Group included as a third objective for the Footprint Study the extension of these tracer element analyses to western Pierce County to evaluate likely sources for arsenic and lead. Therefore, selected samples will be analyzed for a set of additional tracer elements in addition to arsenic and lead (see Sample Analyses in section 6.0 below). Previous tracer element studies in King County included rural Vashon Island locations as well as mainland locations in the Seattle metropolitan area. The Footprint Study will provide results for an additional urbanized area with a different mixture of industries and possible confounding sources for tracer element evaluations. It also will include areas closer to the smelter than those in King County and could extend the

[1]Criteria for defining boundaries for the Tacoma Smelter Plume Site were not developed by the Work Group. Defining such criteria will be important because, given local variability in soil concentrations, the distinction between areas above and below MTCA cleanup levels is not a "bright line" distinction with a clear and simple demarcation between two well-defined zones.

concentration range over which tracer analysis results are available.

2.4 Issues Not Addressed in This Study

The primary objective of evaluating spatial patterns in soil contamination over a relatively large area (i.e., at a regional scale) should be differentiated from alternate goals that are not part of this study. For example, the sampling density at a sampled property in this study is not intended to "fully characterize" contamination at that property - where "fully characterize" might be understood to mean providing adequate sampling to support a determination of final cleanup actions (as is being done, for example, in more detailed sampling for residential properties at the Ruston/North Tacoma and Everett Smelter sites). Local variability will be considered in the study design by frequently collecting samples from more than one boring at a location, which will provide an increased probability of including one or more "higher" values from the locally heterogeneous distribution of values (see Selection of Sampling Locations in section 5.0 below). The objective of evaluating spatial patterns on a regional scale, however, requires less sampling density (i.e., can accept somewhat larger sampling errors) than final cleanup decisions on a property-by-property basis.[2] It should be noted that the upper-bound results from the characterization of regional contamination patterns may underestimate somewhat the maximum values that would be found by detailed property-by-property sampling because of lower sampling density, and consequently greater sampling error.

[2]For any fixed number of samples, the tradeoff being evaluated for the design is more intensive sampling at each selected location versus sampling at a larger number of locations. Note that no increase in sampling intensity at a property will overcome limitations in the representativeness of that property if it is atypical of its locale - for example, a residential property where soil grading, excavation, or importing of fill material results in atypically low levels of residual soil contamination to the depth intervals sampled in the study. On the other hand, a single boring location may be unrepresentative of a sampled location. The Work Group considered these tradeoffs between intensity of sampling and number of locations sampled in developing the study design.

The Footprint Study is also not intended to provide a means of predicting or interpolating specific contaminant concentrations at unsampled properties. The regional information from this study should be useful to establish reasonable ranges within which property-specific contamination levels would occur in different parts of the study area. For example, in areas close to the former smelter soil arsenic values from background to several hundred ppm might occur, while at greater distances values between background and 50 ppm might be reported. In this sense, the results of the Footprint Study will be useful to focus further studies and activities within those regions where soil contamination is greatest. However, local variability in soil contamination has repeatedly been demonstrated to be significant, especially among developed properties (where property-specific development histories affect current soil contamination levels). Given that variability, predictions beyond reasonable and often quite broad ranges of soil contamination to specific values should be avoided. Property-by-property sampling has typically been found to be necessary to establish contaminant levels at specific properties.[3]

There has been considerable interest in defining background concentrations of arsenic, and other metals, in the Puget Sound region (see Washington State Department of Ecology 1994). Local soil background sampling has been performed in Pierce County for, among other sites, the South Tacoma Field Superfund site, Fort Lewis, the former DuPont Works site, and the University Place Water Tanks site. The large spatial extent of Tacoma Smelter impacts makes local determination of natural background (as opposed to area background) soil concentrations for arsenic, particularly in surface soils, problematic in western Pierce County.[4] The Work Group determined that the Footprint Study would focus on defining patterns in the magnitude and extent of soil contamination over a large defined study area but would not include a specific objective of determining background concentrations.

3.0 Overview of Study Design

This section briefly introduces the major elements of the study design. Detailed discussions follow in sections 4.0 through 6.0.

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[3]For example, cleanup actions at residential properties in Ruston/North Tacoma and at the Everett Smelter site are both based on property-by-property sampling, which demonstrates significant variability even for adjacent properties. Ecology is developing voluntary sampling guidance, as part of its area-wide contamination initiative, to provide a documented approach for self-testing of soil contamination by property owners.

[4]Even at concentrations below the MTCA cleanup level of 20 ppm there may be low-level impacts from smelter emissions affecting true natural background concentrations. Thus, sampling in areas "beyond the site boundary" would not necessarily be an appropriate design for a background study.

A hierarchic process was followed in developing the study design. The principal hierarchy stages include:

- Study Area definition
- identification of Candidate Sampling Areas within the study area
- defining Sampling Zones based on location with respect to the former smelter and dominant land cover, with detailed sampling design varying by Zone
- selecting properties to be sampled
- selecting boring locations on selected properties
- selecting depth intervals to be sampled

The Work Group determined early in the design process that a relatively large study area should be included, based on historic study results and the findings in the King County studies on the extent of soil contamination downwind of the smelter. Approximately 200 square miles of western Pierce County, including areas west and north of I-5, are included in the Footprint Study.

For the selection of candidate sampling areas, properties to be sampled, and specific boring locations, a series of exclusion and/or preference criteria was applied. These criteria are discussed for each relevant level of the sample design hierarchy (see section 5.0). The primary reasons for using exclusion and preference criteria were to avoid artifacts (the occurrence of non-smelter related soil contamination, or sampling locations where one or more factors make them non-representative of likely smelter effects) and to focus sampling on the larger concentrations that may be present across the study area, reflecting the objective for defining reasonable upper bounds for magnitude and extent.

Sampling soils in relatively undisturbed areas such as areas with mature forest cover is preferred for initial surveys to determine the magnitude and extent of contamination from Tacoma Smelter emissions. This approach was used in the initial surveys of Vashon-Maury Island and the King County Mainland. Such undisturbed soils better represent upper-bound contaminant concentrations (development and soil disturbance dilutes or removes contaminants); contaminant depth profiles are simpler at undisturbed properties; and sampling can be more cost-effective than at disturbed properties because the contamination patterns are simpler and often less variable on a local spatial scale. However, within substantial portions of the urbanized Pierce County study area such wooded areas are almost nonexistent (or, if present, occur only on steep slopes along shorelines or in ravines whose representativeness is doubtful and which therefore are excluded from sampling). The Work Group determined that adequate spatial coverage to evaluate soil contamination patterns in western Pierce County could only be achieved

by including sampling of non-forested properties in substantial portions of the urbanized mainland (e.g., north Tacoma to Lakewood). As a result, two types of Sampling Zones were defined based on dominant land cover: **undeveloped** Zones, where extensive forested areas are present, and **developed** Zones with primarily urban development patterns.

Properties sampled in the Footprint Study will include **undisturbed** (i.e., forested) properties and **disturbed** (i.e., residential) properties. (The terms undisturbed and disturbed, applied to specific properties, are used to reflect characteristic patterns of soil disturbance relevant to sampling decisions, representativeness, and data interpretations. Note that very large properties may include both undisturbed and disturbed areas, such as forested acreages versus cleared fields and lawns. If undisturbed areas large enough to sample exist, the property will be designated undisturbed for the purposes of this sampling design). Undisturbed properties are extensive enough in undeveloped sampling zones to provide adequate spatial coverage for mapping. Therefore, only undisturbed properties will be sampled in undeveloped zones. To the extent they are available, undisturbed properties will also be sampled in developed sampling zones to provide best estimates for upper bound soil concentrations. However, suitable undisturbed properties occur very infrequently in these developed zones; most sampling locations in the developed zones will reflect disturbed properties.

Developed sampling zones include a variety of land use types. Thus, residential properties, vacant (cleared) lots, parks and playgrounds, schools, and commercial properties would all be considered disturbed properties in comparison to forested lands. The specific development and soil disturbance history of each property contributes to its current pattern of soil contamination from smelter emissions. The Work Group concluded that in many respects older residential properties are preferred among disturbed property types to characterize the magnitude and extent of smelter-related contamination where forested land cover is absent. (Residential properties are the dominant land use within the developed zones of the study area). While certainly not true in every case, the most significant soil disturbance may often be associated with the initial construction of a home. Older homes may therefore on average represent a longer period of time post-construction for accumulation of soil contaminants from smelter emissions through smelter closure in 1986. A relationship between soil arsenic concentration and age of home was found in Ecology's University Place sampling of residential properties (see Washington State Department of Ecology 2001a).

Disturbed (residential) and undisturbed (forested) properties clearly represent different populations with respect to possible soil contamination from smelter emissions, and it will be essential to consider these differences when evaluating the results of the study.[5] Inclusion of both property types was judged necessary to obtain the required coverage of the Pierce County study area.

[5]See, for example, the results from sampling at selected Child-Use Areas and adjacent Forest Fringe areas on Vashon-Maury Island (PHSKC and Glass 2001).

Resource constraints for the Footprint Study limit the number of soil samples that can be collected and analyzed. Part of the sample design problem was therefore to address sample allocation questions, balancing choices for the number of properties sampled, the number of borings per property, and the number of depth intervals per boring within and across Sampling zones. Patterns observed in prior studies for local variability of contaminant concentrations and soil depth profiles were considered in choosing to include multiple borings at most sampling locations and to limit the number of depth intervals sampled, focusing on near-surface soils.

In recognition of the demonstrated local variability in soil contamination levels and an objective of producing a reasonably stable regional-scale mapping of soil contamination, the Work Group determined that multiple borings should be sampled at most locations. The maximum contaminant concentration reported from multiple borings at a sampled property will be used as an indicator for upper-bound values, for the purposes of regional-scale mapping.

It is not necessary to fully define contaminant depth profiles (e.g., to characterize the depth to which background concentrations are exceeded) in this study. The primary objective for depth profiling is instead to characterize the higher concentrations to be found in the depth profile at each boring. Previous studies support an assumption that these higher concentrations are commonly to be found within the top 6 inches of the soil column; with only infrequent exceptions, undisturbed (forest) soils are expected to show this pattern, and in the Vashon-Maury Island Child-Use Areas study approximately 70 percent of the sampled Decision Units, representing disturbed properties, still showed this pattern (based on sampling down to 22 inches). Therefore, the Work Group determined that the standard depth profiling in the Footprint Study would include two depth intervals at 0-2 and 2-6 inches, with some selected locations (primarily at residential properties) also sampled at a third depth interval of 6-12 inches to check the possible occurrence of depth profiles not consistent with the assumption underlying the study design.[6]

4.0 Study Area Definition

A study area of approximately 200 square miles was chosen by the Work Group for the Pierce County Footprint Study. Study area boundaries were chosen after compilation and review

[6]Under various scenarios - for example, the importation of significant depths of fill soils - the maximum soil contaminant concentration could occur at depths well below 12 inches. The cost of extensive depth profiling at all sampled locations was prohibitive under project resource constraints, and incompatible with other study objectives. Regional-scale mapping can tolerate some sampling errors (e.g., not sampling deep enough to define the maximum concentration in a boring) as long as such errors are not too frequent. The regional-scale mapping and its interpretation reflect large assemblages of sample results more than individual sample results.

of historic studies in Pierce County and evaluation of wind rose information on dominant wind directions (for plume transport from the smelter tall stack) to determine areas most likely to be affected by smelter emissions. The study area was extended to adjacent county line boundaries in western Pierce County to complete at least a pilot scale investigation of all parts of western Pierce County, and in the expectation of developing some preliminary information on likely boundaries for the Tacoma Smelter Plume site in Pierce County.

4.1 Review of Historic Studies

Previous studies with soil sampling and analysis data, or other types of information relevant to the possible extent of Tacoma Smelter impacts in Pierce County beyond EPA's ROD boundary, were identified and compiled. Copies of reports and data sets were made for both TPCHD and Ecology project files. In all, more than two dozen historic studies were located from G. Glass files and Ecology files; some contact calls to other agencies and area colleges were also made to seek additional information. A listing of these previous Pierce County studies is included under a separate heading in the references section (see section 9.2).[7]

A few of the historic studies provided information other than soils data; for example, Lutrick (1971) used a mobile measurement instrument to record locations of ground-level impacts of the Tacoma Smelter plume, and a regional study using bees as biomonitors of pollution (Bromenshenk et al. 1985) included portions of northwest Pierce County. The information from these non-soils studies documented spatial patterns of smelter impacts that could reasonably be associated with elevated soil contaminant levels. Most of the identified historic studies, however, provided soil sampling and analysis results.

Soil sampling results are available from historic studies for large portions of Pierce County, albeit often with low sampling density or other limitations for determining the magnitude and extent of soil contamination from smelter emissions. Areas south and east of I-5 were broadly sampled in EPA's Urban Soils Monitoring Program studies and for pre-application testing in the City of Tacoma's biosolids program. Multiple studies have included areas north and west of I-5, with some samples collected in areas as far as the Browns Point/Northeast Tacoma area east of the smelter, the Key Peninsula west of the smelter, and DuPont to the southwest. The number of soil samples per study varied greatly, from fewer than 10 to more than

[7] It is likely that some additional studies exist, but the Work Group concluded that the effort needed to identify and obtain them would not significantly improve the results of the review of historic data. Such additional studies could involve, for example, student/academic studies, investigations by local governments, and property screening evaluations by private parties. Soil sampling results from a class action lawsuit against ASARCO (Branin et al. v. ASARCO), in areas beyond EPA's ROD boundary that are included in the Footprint Study, were sealed upon settlement of the case and are not available.

100. Arsenic was commonly analyzed, sometimes as the only analyte; the inclusion of other elements varied widely from study to study. The sampling and analytical protocols also varied significantly among the historic studies, as did the documentation of data quality reviews and findings. For example, the types of land uses sampled varied from relatively undisturbed woodlands to residential lawns to gardens, the vertical depth intervals sampled were not comparable across studies, and horizontal compositing of samples from multiple locations before analysis was used in some studies but not others. These differences among studies affect the meaning and representativeness of the reported numerical results and need to be considered in evaluating the cumulative information from historic studies.

TPCHD used the county GIS software to map selected results for soil arsenic and lead from the accumulated historic studies. For example, where the data densities were very high only the largest concentrations were mapped. These data summaries and GIS maps were provided to Ecology as a deliverable (subtask 7.1.2) under the SHA grant scope of work (see Figure 1).

The Sampling Design Work Group reviewed the cumulative information from historic studies. Decisions on study area boundaries and sampling densities were influenced by the historic data. Arsenic concentrations exceeding the MTCA cleanup level for unrestricted land use of 20 parts per million (ppm) have been reported in previous studies for the Browns Point area, on the Gig Harbor Peninsula, on Fox Island, in South Tacoma and University Place, and as far distant as near DuPont, about 15 miles southwest of the smelter (in the second most frequent downwind direction, after northeast, according to annual wind roses). The occurrence of smelter-related soil contamination at distances of 15 miles or more in western Pierce County would be consistent with the findings of the studies already completed by Ecology and PHSKC in King County, in the dominant northeast wind direction from the smelter. The cumulative historic results for areas east and south of I-5 suggest that soils are typically below the MTCA cleanup level of 20 ppm there (although the limitations in spatial coverage, sampling density, and sampling protocols should be recognized). The limited sampling results for the Key Peninsula also suggest that the low wind frequencies to the north and northwest have limited impacts on soil arsenic concentrations in that region. The low density of soil sampling for most areas covered by the historic data sets is almost certainly not adequate to produce stable maps of soil contamination (in the sense discussed by Miesch 1976a and Miesch 1976b; see the discussion in Glass 1999); that is, of course, the basis for proceeding with the Footprint Study. Therefore, the historic data are not assumed to identify all areas where MTCA cleanup levels may be exceeded.

Studies evaluated by EPA in developing the ROD for the Ruston/North Tacoma cleanup for areas within approximately one mile of the Tacoma Smelter included relatively dense sampling of surficial soils (see, for example, Black & Veatch 1988 and Bechtel Environmental, Inc. 1992). The property-by-property sampling being performed by ASARCO as part of the remedial actions within the ROD area provides much more detailed information for that region closest to the smelter (see TPCHD 2001). The current Pierce County Footprint Study to investigate the magnitude and extent of soil contamination will not include any sampling within EPA's ROD boundary. Data from ASARCO's property cleanup actions within the ROD

boundary, in combination with data to be collected in the Footprint Study, will help define the large-scale pattern of soil contamination from smelter emissions within western Pierce County.[8]

4.2 Selection of Study Area Boundaries

The Work Group decided to perform this initial Pierce County survey in a single phase, rather than as a sequence of studies (e.g., at increasing distance intervals from the smelter). The previous King County studies have shown that soil concentrations of smelter-related contaminants can be elevated to distances of tens of miles downwind. A wind frequency diagram (see Figure 2) shows that the most frequent wind directions near the smelter, typical of winter months, are to the northeast (Vashon-Maury Island and King County Mainland). The second most frequent directions, often occurring during summer months, are to the southwest (toward University Place and Fox Island). Thus, the dominant downwind direction for Pierce County is approximately southwest from the smelter; information from historic studies in Pierce County is generally consistent with this pattern. As a result, the study area was defined to include a large region of approximately 200 square miles of western Pierce County. As described below, this large study area includes regions to the northwest (Key Peninsula) and east-southeast (Browns Point and Northeast Tacoma area) toward which smelter-area winds blow only infrequently.

The western and northern boundaries of the study area were selected consistent with the objective of completing at least a pilot study to the Pierce County line in those regions. Thus, the study includes areas of western Pierce County to the Thurston, Mason, Kitsap, and King County lines, including the entire Key and Gig Harbor peninsulas and the Browns Point and Northeast Tacoma area. The eastern and southern study area boundaries were selected after reviewing information from historic studies, considering wind roses and likely plume transport directions, and taking account of practical resource constraints. Historic studies in areas east and south of I-5 have generally shown low soil arsenic concentrations, although few samples are available for areas close to I-5 (see Figure 1). The west-southwest to east-northeast alignment of much of the I-5 corridor is also roughly parallel to the dominant transport direction in Pierce County as shown by the wind rose. The Work Group determined that the study area would include that portion of Pierce County to the north and west of I-5. This choice does not reflect a final determination of the southern or eastern boundaries of the Tacoma Smelter Plume site within Pierce County.

[8]The overall spatial pattern is a combination of the effects of low-level, fugitive emissions and tall stack releases. Those two classes of releases have different spatial impacts, with fugitive emissions dominating in areas close to the smelter and tall stack releases dominating at greater distances.

The study area defined in this manner includes regions up to about 16 miles from the former Tacoma Smelter tall stack (see Figure 3). Areas to be sampled include the following: the entire Key Peninsula and Gig Harbor Peninsula, north to the Kitsap County line; Fox Island, McNeil Island, and Anderson Island; the Browns Point area and the Northeast Tacoma highlands overlooking the Tacoma Tideflats; and Pierce County mainland areas west of I-5 from North Tacoma (including Point Defiance Park) to University Place, Fircrest, South Tacoma, Lakewood, Steilacoom, parts of the Fort Lewis military reservation, and DuPont.

5.0 Selection of Sampling Locations

This section describes the sequence of steps used to select sampling locations for the Footprint Study. It also describes how the sampling design is varied for different parts of the overall study area; the same sampling approach is not used at all locations. The basic sampling design applies a series of sampling grids with different spacing (i.e., sampling densities) in different parts of the study area to identify locations for sampling. A small number of additional targeted sampling locations is also included, outside of the grid locations. The exclusion criteria and preferences for selection of specific properties to be sampled are discussed at each level of the selection process. A summary of the developed sampling design is provided in Table 1.

5.1 Candidate Sampling Areas

Some sizable portions of the overall study area are considered unsuitable for inclusion in the Footprint Study and are excluded. There are several reasons for exclusion of such areas: 1) access is restricted in some cases; 2) substantial soil disturbance makes some areas unrepresentative; 3) extensive soil sampling has been or is being performed; 4) other confounding sources are known or suspected to occur locally (as at other designated and sizable cleanup sites); 5) surface soil samples are unavailable (e.g., areas whose surface is entirely paved or covered by structures); and 6) the presence of extensive lakes, wetlands, or floodplains.

Parts of the study area excluded from sampling include the following:

- the industrialized Tacoma Tideflats area
- the commercially developed downtown Tacoma area
- a setback of 500 feet from the heavily traveled I-5 transportation corridor (where soil lead may be heavily influenced by emissions from leaded gasoline)
- the Tacoma Smelter and Ruston/North Tacoma ROD sites being addressed by EPA under Superfund

- the South Tacoma Field, Tacoma Landfill, and Former DuPont Works cleanup sites
- restricted portions of the west Fort Lewis reservation
- the Steilacoom gravel pit
- the McNeil Island Corrections Center restricted areas
- Nisqually Flats floodplain areas
- the Tacoma Narrows Airport
- the Point Defiance Zoo
- shopping malls and other extensive paved areas (e.g., industrial and warehouse areas)
- numerous areas of lakes and marshes (with the largest such area being in the Lakewood/Steilacoom/Fort Lewis/DuPont region)

Those parts of the study area not excluded based on these (large-scale) exclusion criteria are considered Candidate Sampling Areas for the Footprint Study.

5.2 Sampling Zones

The Pierce County study area is large; the magnitude of smelter impacts on soils within this study area is expected to vary considerably with direction and distance from the smelter. To meet the study objectives, it is more cost effective to allow for different sampling approaches in different parts of the study area. This type of sample allocation approach can also take into account the characteristic differences between developed and undeveloped regions. Therefore, the total study area is subdivided into a number of sampling zones.

Much of the mainland portion of the Pierce County study area reflects dense urban development and land use, where forested properties occur very infrequently. Sampling in those mainland areas was nevertheless deemed essential to provide adequate spatial coverage for the Footprint Study. Thus, Candidate Sampling Areas can be divided into two categories based on dominant land use and land cover: mainland regions where woodlands are infrequent (for which the general term "developed" will be used, representing all types of land cover where trees are absent, including vacant lots), and remaining regions where forest cover occurs frequently (for

which the general term "undeveloped" will be used, recognizing that almost all areas, at a minimum, have been logged). These two categories were combined with distance and direction information from the Tacoma Smelter to identify six portions of the total study area, or zones, which could be assigned different sampling designs (see Figure 3). In sampling design terms, this reflects a stratification of the study area.

Three developed sampling zones, located generally south-southwest of the smelter (except for Browns Point and Northeast Tacoma), are designated D1 (North Tacoma), D2 (Northeast Tacoma and University Place), and D3 (Lakewood) in order of increasing distance. Undeveloped sampling zones U1 (Point Defiance Park, southeast Gig Harbor Peninsula, and southeast Fox Island) and U2 (southwest Gig Harbor Peninsula, northwest Fox Island, southern Key Peninsula, Anderson and McNeil Islands, and Steilacoom and DuPont areas), generally to the west-southwest of the smelter, similarly reflect increasing distances from the smelter. Undeveloped sampling zone U3 (northern Key and Gig Harbor Peninsulas) is located to the west-northwest of the smelter in a direction of infrequent transport winds according to the wind frequency diagram (see Figures 2 and 3).

5.3 Sample Allocation Principles

Practical resource constraints for the study (e.g., budget, sample collection effort) were considered by the Work Group as part of the study design process. The primary factors affecting overall project scope and cost, once the study area was defined, are the number of properties sampled (or sampling density), the use of multiple borings (clusters) at selected sampling locations, and the number of depth intervals sampled. Meeting a defined project constraint for the study (e.g., total number of samples analyzed) is essentially a design allocation problem across these factors.[9] A primary interest in addressing sample allocation decisions is how to obtain the most information relevant to study objectives for a fixed (maximum) number of samples to be collected.

Various combinations of grid spacing (see Section 5.4), number of borings per location (see Section 5.6), and depth intervals sampled (see Section 5.7) were used for each of the six defined sampling zones. In considering the sample allocation decisions, the Work Group took note of three aspects of the likely distribution of soil contaminant levels across the study area: 1) at the spatial scale of the study area, concentrations are likely to generally decrease with increasing distance from the smelter; 2) soil contamination is expected to show variability locally among closely-spaced sampling locations and properties, with the overall range of soil concentrations greatest in those areas where smelter impacts are likely to be highest; and 3) the patterns of soil contamination (e.g., depth profiles) on disturbed properties are likely to be more

[9]For example, the same sample count could be achieved by various combinations of the number of locations sampled, the number of borings per location (and frequency of use of boring clusters), and the number of depth intervals sampled per boring.

complex than on undisturbed properties. Accordingly, the sampling design generally assigns greater sampling density to closer as opposed to more distant regions, and to disturbed as opposed to undisturbed properties, reflecting the Work Group's conceptual model of the likely distribution of soil contaminants. These allocation principles support the primary study objective of mapping the spatial pattern of smelter-related soil contamination (and not, for example, determining final boundaries for the Tacoma Smelter Plume Site). The specific allocation decisions are discussed below for each sample design element: grid spacing, number of borings, and depth intervals sampled.

5.4 Sampling Grids

The basic approach used to select sampling locations is application of a sampling grid. That approach is appropriate for regional-scale mapping of soil contamination. While research studies have shown triangular grids to be somewhat more efficient for spatial coverage, ease of application determined that square grids would be used for this study.

Grid sizes vary between 2,000 and 8,000 feet across the six defined sampling zones (see Table 1 and Figure 3). Larger grid sizes reflect lower sampling densities, by a squared relationship (i.e., a four-fold increase in grid size represents a sixteen-fold lower sampling density, in grid locations per square mile). The less dense the grid, the larger the potential error for determining upper-bound concentrations (given relatively large local variability). The assigned grid sizes generally increase at more distant zones. This principle reflects a greater tolerance for error (low bias) in regions farther from the smelter, where the overall range of soil concentrations is very likely limited compared to closer areas. It drives the sample allocation toward better definition of soil contamination in those areas where smelter impacts and resulting exposures (and also local variability) are likely to be greater. The effective grid sizes, after elimination of some sampling locations because access agreements cannot be completed or because additional exclusion criteria apply (see Section 5.5), will be somewhat larger than these nominal grid sizes. For comparison, the effective grid sizes for the entire study areas in the initial Vashon-Maury Island survey were on the order of 2,500 feet and in the initial sampling of the King County mainland approached 10,000 feet. The grid sizes selected for the Pierce County study are thus comparable to those used previously in King County. The largest grid size (8,000 feet) for the Pierce County Footprint Study is assigned to zone U3 where only a pilot-scale study is intended.

TPCHD used Geographic Information System (GIS) software and Pierce County databases to lay out the sampling grids (see Figure 3). Grid locations are identified by choosing random grid starting points and then applying the appropriate grid spacing for each sampling zone.

5.5 Selecting Properties for Sampling

Most of the properties to be sampled in the Footprint Study are selected from the sampling grid layouts in each sampling zone. A small number of additional, targeted sampling locations are selected after grid layout properties are identified. The procedures for each approach to selecting properties to be sampled are described below.

5.5.1 Selecting Properties at Grid Locations

For the purposes of this study, it is not essential that the property located exactly at a grid location be sampled. The grid layouts are instead used to establish a system for spatial coverage of the sampling zones. Properties "in the vicinity" of the grid locations can provide suitable information for defining the magnitude and extent of soil contamination over the study area. Often the property exactly at a grid location will not have the desired characteristics for sampling; for example, it may not have the required forest cover for sampling in an undeveloped sampling zone, although nearby properties do have forest cover. The selection of properties at grid locations therefore proceeded initially by looking within a distance from the exact grid location equal to one-quarter of the grid spacing for properties with favorable characteristics. To account for uncertainties in securing access agreements, multiple properties (up to five) that could be sampled were identified for each grid location.[10] As final selections were made, the restriction to distances no more than one-quarter the grid spacing dimension from a grid location was relaxed somewhat in a small number of cases to allow for more favorable selections.

Both exclusion and preference criteria are used in selecting properties for possible sampling. The purpose of the exclusion criteria is to avoid sampling in unrepresentative locations, where smelter impacts have been unusually disrupted or eliminated or where other arsenic or lead sources may result in artifacts. These criteria are applied at a spatial scale that is smaller than the initial exclusion criteria used to determine Candidate Sampling Areas within the overall study area. General exclusion criteria included local road and rail line setback requirements, small lakes and wetland areas, floodplains associated with local creeks, steep slopes along ravines and shoreline bluffs, and paved areas. In the undisturbed sampling zones, all non-forested areas are initially excluded, assuming that forested areas are extensive enough to provide the information required for mapping soil contamination. (Both Pierce County GIS orthophotos and recent airphoto coverage purchased commercially for this project were used to determine areas with forest cover). In the developed sampling zones, properties that are neither residential nor forested (e.g., industrial and commercial properties, schools, play fields, or vacant lots) are excluded. Residential properties where homes were built after 1970 are also excluded

[10]TPCHD will send access agreements to the multiple property owners selected for each location. Additional properties may be selected if access cannot be obtained at any of the original list of properties. No more than one property at a study location will ultimately be sampled.

because of the short period until smelter closure in 1986 for accumulation of contaminants from smelter emissions in soils.

Preference criteria are also used to guide selection of properties. In undeveloped sampling zones, topographic information on elevations and slopes was reviewed, with higher elevations and slopes facing the smelter and not shielded by nearby topographic relief preferred. Larger contiguous areas with forest cover are also preferred to smaller, more isolated forested areas where incidental disturbance is considered more likely. In developed sampling zones, residential properties with the oldest homes are preferred; in cases where many homes had the same age, random selections of up to five properties are used. In a few instances, one or more wooded properties were identified near grid locations within developed sampling zones. They were selected whenever available, because relatively undisturbed wooded properties are likely to represent the greatest impacts from smelter emissions. At grid locations where both forested and residential properties are identified, the forested properties are preferred for sampling.

5.5.2 Additional Targeted Sampling Locations

A small number of targeted sampling locations was added to the study design to supplement the grid locations. These targeted locations were added to increase the likelihood of including locations with comparatively greater smelter impacts within the Footprint Study. This will improve the mapping of the possible magnitude of smelter impacts. The targeted locations arose under one of two circumstances: 1) the occurrence of small forested areas within the developed sampling zones that were not otherwise identified for sampling by the sampling grids, and 2) the occurrence of potential high-impact areas, based on slope characteristics and elevations, that were not otherwise identified for sampling within the undeveloped sampling zones. (Note: Table 1 estimated sample counts do not include these additional targeted locations; see the Field Sampling Plan for adjusted sample counts after selection of all sampling locations).

The Work Group decided that to the extent they are available forested areas within the developed sampling zones should be sampled. Such forested areas occur only sparsely within these highly-developed areas of the Pierce County mainland. Many of them were not identified by the grid layouts. Forested areas of more than de minimis size were identified from recent airphotos of the study area and included unless excluded by one or more of the exclusion criteria (e.g., steep slopes). All forested properties added in zones D1, D2, and D3 will be sampled using the same approach used for zone U1 sampling (see Table 1 for zone U1 design). Identified forested areas in the developed sampling zones will be sampled even if they have been sampled previously (e.g., see City of Tacoma and Glass 1999).

In the undeveloped sampling zones, the generally larger grid spacings resulted in some hilltop locations, where smelter impacts could be comparatively greater, not being included in the grid layouts. A small number of such hilltop locations was therefore added to the study. The

sampling approach for the sampling zone where the added location occurs (U1, U2, or U3; see Table 1) will be used for each such targeted location.

5.6 Selecting Boring Locations at Sampled Properties

Detailed sampling at residential properties in Ruston/North Tacoma and near the Everett Smelter site has shown considerable variability in soil contamination within a single property. Therefore, sampling from multiple borings per property was chosen for disturbed properties. The Work Group determined that within the practical resource constraints for the study, four borings would be used at each disturbed property sampled in zones D1, D2, and D3. That number of borings was a compromise between better characterization of soil contamination within a property and sampling at a greater number of properties (i.e., at a smaller grid size and greater density of sampling locations).[11]

At undisturbed properties, local variability will be addressed by including "clusters" of up to three borings per sampling location; this type of spatial scale sampling was also used in the initial Vashon-Maury Island and King County mainland studies. Clusters of three borings per sampling location were used at all King County mainland sampling locations, but for only a percentage of the Vashon-Maury Island locations. Resource constraints limit the number of clusters that can be used in the Pierce County Footprint Study. A sliding scale with distance will be used, with three borings per location in zone U1, two borings per location in zone U2, and a single boring for the pilot-scale study in zone U3. Collecting data at multiple borings increases the probability that one or more of the reported concentrations will come from the upper part of the locally-variable distribution of values. The amount of variation is expected to be greatest in areas closer to the smelter. Therefore, the allocation for number of borings per location is biased toward the zones closer to the smelter. An L-shaped layout (with randomly chosen directions) for three borings will be used in zone U1, matching the approach used in previous studies, with inter-pair distances of 300 and 50 feet if the wooded areas are sufficiently large (and smaller as

[11]No matter how many borings are used at a single property, there remains the question of how representative of the region that one property may be; individual property histories are believed to be important in determining the level of soil contamination at each property (and there may also be differences among properties in original contaminant deposition). Therefore, maintaining an adequately small grid spacing (for map resolution) was an important consideration for this study design. In general, spatial patterns of soil contamination will be evaluated using the results from multiple sampling locations, not single sampling locations.

required if they are not). The design distance between the two borings in zone U2 will be 300 feet.

The specific boring locations will be selected by TPCHD sampling team members in the field. For undisturbed properties, boring locations should be selected with setbacks from roads, rail lines, any painted structures, and any other man-made features that could introduce artifacts from non-smelter sources for metals. Any areas that show evidence of soil disturbance should be avoided. Characteristics favoring selection and indicating little disturbance include a well-developed forest duff layer with no rocks or mineral soils visible on the surface, an intact understory of forest vegetation, a lack of hummocky terrain features, and the presence of older (larger) trees. Borings should not be located on wetlands, slopes subject to significant erosion, animal or human trails, burned areas, areas with evidence of recent logging, or areas where uprooted trees (e.g., wind blowdown) are obvious. The field sampling team should also consider the possible influence of local topography - slopes and elevations - on deposition of smelter contaminants by orienting themselves toward the smelter at each sampling location and avoiding lee slopes if feasible. At smaller forested areas, particularly those within the three developed sampling zones, recognition of potential soil disturbance will be particularly important to obtain soil samples representative of long-term deposition from smelter emissions.

Residential properties in developed sampling zones will present much smaller areas within which to select boring locations. To the extent possible, locations potentially subject to artifacts from other sources for metals should be excluded. Thus, locations near treated wood (play structures, fences, planting area borders), painted structures, and local roadways should be avoided. To the extent that it can be determined (from visual observations or discussions with residents), areas with the least soil disturbance are preferable for sampling; these may often be lawn areas. Borings should not be located in gardens, children's play areas (e.g., sand boxes), or other areas likely to have experienced substantial soil amendment, tilling, excavation, or regrading. Boring locations should typically be divided between front and back yards where they can be defined; front and back yards may have quite different development histories, which are often not well-documented, so it cannot be known in advance which yard has the higher concentrations of smelter-related contaminants. Borings should be separated sufficiently to provide reasonable spatial coverage of the non-excluded portions of the residential property.

5.7 Sampling Depth Intervals

Two depth intervals - 0-2 inches and 2-6 inches - will be sampled at all borings to characterize soil contamination. At undisturbed, wooded locations in the King County mainland study, only about 10 percent of sampled locations had maximum arsenic or lead concentrations at depths greater than 6 inches, and some of those maximum concentrations were only marginally greater than concentrations within the top 6 inches. At disturbed properties in the Vashon-Maury Island Child-Use Areas study, about 30 percent of sampled Decision Units had maximum concentrations below 6 inches. Property development and soil-disturbing actions are expected to

result in more frequent occurrence of complex depth profiles.

In the Footprint Study, a third depth interval from 6-12 inches will be sampled at selected locations to provide additional depth profile information. Project constraints preclude sampling all borings for a third depth; the adopted approach therefore reflects a sample allocation decision. Additional depth profiles will be collected in all three developed zones, with decreasing percentages of locations selected as distance from the smelter increases (40%/30%/20% in zones D1, D2, and D3, respectively). Among the undeveloped zones, only U1 will include added depth profiling (at 25% of locations). Additional depth profiling will thus focus on developed areas and those undeveloped areas closest to the smelter, where the range of soil contaminant concentrations is expected to be greatest. Most of the samples collected at 6-12 inches will be from developed properties where more complicated contaminant depth profiles are expected because of soil disturbing activities from property development. At the locations selected for additional depth profiling, all borings will be sampled at the 6-12 inch depth interval. Locations selected for additional depth profiling should represent a random subset in each zone and should provide spatial coverage of that zone.

5.8 Sampling Design Summary

The study design parameters by zone and the estimated numbers of sampling locations and soil samples (for grid sampling only) are summarized in Table 1. The three developed sampling zones, which account for about 27% of the total study area, include almost 72% of the total sample count, demonstrating the greater sampling density assigned to developed, and closer, regions.

The number of sampling locations and number of soil samples shown on Table 1 are only design-level estimates. The final number of grid locations per zone will be affected by the irregular geometry of the sampling zones and final grid layout. Added targeted locations are not yet included in the estimates. Additional exclusion areas, not considered yet in the summary table or the estimated sizes of the sampling zones, will apply. The proportion of access requests that will be granted is unknown; some positive rate of refusal is expected. If repeated attempts to get access agreements at properties near a grid location are unsuccessful, that sampling location may be lost to the study.

Overall, the sampling design as reflected in Table 1 includes a degree of "overdesign"; some decrease in the total number of samples actually collected and analyzed is expected from refusals of access and the application of exclusion criteria, and can be accommodated while still meeting the study objectives.

6.0 Sample Analyses

Chemical analyses of collected soil samples will include two sets of analytes: 1) arsenic and lead, and 2) additional selected tracer elements. All samples will be analyzed for arsenic and lead. Only about ten percent of samples will be analyzed for the additional tracer elements, with tracer samples selected after evaluation of the initial arsenic and lead results. The magnitude and extent of smelter-related contamination will be evaluated primarily based on arsenic results, and secondarily based on lead and tracer results. Analyses for lead and the additional tracer elements will be used for evaluating the smelter as a source for observed arsenic contamination.

6.1 Primary Study: Arsenic and Lead

Arsenic and lead are recognized as two of the primary smelter-related contaminants of interest. Arsenic is generally considered the indicator contaminant for smelter emissions; cumulative arsenic emissions were very large, naturally occurring soil arsenic concentrations are relatively small (on the order of 5 ppm), and no other substantial arsenic emission sources have been identified in the region. Arsenic is also of greatest interest for potential human health threats and exceedances of MTCA cleanup levels. Lead was also released from the smelter in substantial amounts. In addition to the possible occurrence of lead concentrations in soil exceeding MTCA cleanup levels, lead has been shown to be one among several useful tracer elements associated with smelter emissions. Unlike arsenic, however, other significant sources of lead are known (e.g., historic use of leaded gasoline) that are likely to confound interpretations of the soil lead results from this study, especially in highly developed areas where historic traffic counts were high and an "urban lead plume" occurred. The Work Group decided to include lead analyses for all soil samples in the Footprint Study, notwithstanding such potential confounding factors. The same decision was made previously for the King County mainland study. The combined data sets from all Tacoma Smelter Plume studies, including both urban and rural sampling locations and a large number of samples, will offer an opportunity to evaluate comparative arsenic versus lead concentrations over a large area where both smelter and non-smelter lead sources occur.

All soil samples collected in the Pierce County Footprint Study will be analyzed for arsenic and lead; no samples will be archived without analysis. Soil samples will be analyzed as discrete samples (as submitted from the field) without additional compositing across borings or sampled depth intervals.

Consistent with the protocols in previous studies, and as required under the MTCA Cleanup Regulation (Chapter 173-340 WAC), sample preparation will include homogenizing and sieving the samples with all analyses performed on the fractions <2mm in size. Total (unspeciated) arsenic and lead concentrations will be reported on a dry weight basis; thus, percent moisture (equivalently, percent solids) analyses will also be performed for calculation of dry weight concentrations. The remaining sample materials will be archived after arsenic and lead analyses are completed for possible additional tracer element analyses (see section 6.2 below) or for reanalysis on request after the initial results are reviewed. Tracer element analyses

may require shipment of archived sample materials to a second analytical laboratory. TPCHD will instruct the lab(s) on the disposition of archived sample materials at the end of the study.

Data evaluations will benefit from minimizing the frequency of results reported as not detected (i.e., below the practical quantitation limit, or PQL). Nominal PQL values of about 1 ppm are desirable for arsenic and lead results.[12]

6.2 Tracer Element Study: Source Identification

The analysis of selected samples for additional tracer elements, begun in previous Tacoma Smelter Plume studies, will be continued in the Pierce County Footprint Study. Tracer element results have shown strong correlations with soil arsenic results, demonstrating their usefulness for evaluating likely arsenic source(s). The tracer element analyses will require the lowest practicable PQL values to provide useful data for evaluation; many of the tracer elements occur naturally at concentrations well below 1 ppm.

A two-stage protocol for tracer element analyses will be followed, identical to the protocol from previous studies (report in preparation). An extended list of over 30 potential tracer elements will be analyzed for a small initial set of ten samples (referred to as the "first ten" samples). Arsenic and lead are included in this extended tracers list, allowing comparison with initial sample analyses for arsenic and lead. The purpose of this initial stage is to identify or confirm a small subset of tracer elements for use with the much larger number of stage two samples from this study area. Both of the previous tracer element studies have selected antimony, indium, and bismuth from among a larger set of effective smelter tracer elements, considering the strength (e.g., enrichment ratios) and specificity (e.g., correlations) of the associations among arsenic and tracer elements. Those same three tracer elements will be selected for the Pierce County Footprint Study unless the results of the first stage analyses provide a compelling reason to change to different tracers. The second stage will analyze approximately ten percent of all collected soil samples for three primary tracer elements. A fraction (approximately 15 percent) of the stage two samples will also be analyzed for arsenic to evaluate consistency between analyses (between sample aliquots, and possibly between labs),

[12]The results of ICP-MS and graphite furnace AA arsenic analyses by two laboratories for a subset of samples in previous Tacoma Smelter Plume investigations have shown very good agreement. Therefore, ICP-MS analyses should provide data comparable to previous GFAA results, but with lower PQL values. A few tracer elements (e.g., mercury) may be analyzed by methods other than ICP-MS; see the Quality Assurance Project Plan.

since the tracer element analyses will not be performed on the same subsamples as the initial arsenic analyses. Data evaluations will ultimately combine arsenic results from the initial lab analyses with later tracer element results when assessing the strength of their relationships. Comparing arsenic results from the two analyses will provide support for this approach to data evaluations while avoiding the costs for complete reanalyses of arsenic and lead.

Soil samples will be selected for the tracer element study only after arsenic and lead results are known. The sets of samples for both steps in the tracer element study will be selected using the same principles. Each set of samples will represent widely spaced sampling locations (i.e., provide good spatial coverage over much of the study area), include as broad a range of arsenic and lead concentrations as possible, and include samples from multiple depth intervals in selected borings (since arsenic and tracer element mobility and fate processes may differ, resulting in some vertical separation of different elements within the soil column). The selected samples, particularly at the second stage, may also include some with "anomalous" arsenic and lead patterns, where source identification and the ability of tracer elements to discriminate among sources will be of particular interest.

The overall statistical distributions of arsenic and lead results in the Footprint Study are expected to be right-skewed, with comparatively infrequent higher concentrations (i.e., more lognormal than normal). To meet the objective of having a more uniform distribution of values across as broad a concentration range as possible for tracer analyses, tracer element samples will be selected in a non-proportional manner. A higher proportion of the infrequent higher concentration samples will be chosen, and a smaller proportion of the more frequent lower concentration samples will be chosen.

The order of areas sampled in the early phases of the Footprint Study should consider the need for the "first ten" tracer element samples to provide reasonable spatial coverage across the study area while including representative high contaminant concentrations. The "first ten" tracer samples will be selected when only a fraction (perhaps 15 to 20 percent) of all samples have been collected and analyzed for arsenic and lead. Completion of tracer element analyses within standard soil sample hold times for metals analyses will require timely sample selection and planning for tracer analyses, given the anticipated duration of the overall study.

7.0 Implementation of Sampling Design

The large number of soil samples to be collected and analyzed in the Footprint Study will result in an extended period for sample collection and for completion of all sample analyses and data evaluations. Field sampling activities are expected to begin in about March 2002. Study completion is anticipated by about the end of the year. Field sampling will be performed by a two-person team of TPCHD staff.

TPCHD and Ecology have already started many of the supporting activities to implement

this study design. Implementation activities will include, among others, the following:

- preparation of project plans, including a Field Sampling Plan, a Quality Assurance Project Plan, and a Health and Safety Plan. The project plans will provide details on sample collection protocols as well as laboratory analysis protocols. A system for sample coding will be defined. Quality assurance and data validation steps will also be described.

- contracting with analytical lab(s), a utility locator service, and a data validation contractor.

- completing necessary training for field staff (including training in this study design and study objectives, sampling methods, use of GPS, field documentation, health and safety, and HAZWOPER training).

- selecting specific properties to be sampled and identifying property owners.

- developing access agreements and contacting owners to obtain access for sampling, and also establishing a sequence for sample collection.

- designating specific boring locations and selecting those locations where additional depth profiling will be performed.

- arranging for utility marking as needed.

- designing a database for study results and confirming the protocols for information to be provided for loading into that database.

- purchasing and assembling equipment needed for field sampling activities.
- supporting public information activities including meeting with local governments.

8.0 Data Evaluations

The evaluations of the data from the Footprint Study will be primarily descriptive rather than formal statistical hypothesis testing in nature.

The magnitude and extent of soil contamination will be illustrated by mapping the results by sampling location and coding concentration magnitudes (e.g., color coding by ranges). The patterns by distance and direction from the former smelter will be readily observable in these data maps. Scatterplots of results by distance and direction will also be prepared and will show both the "enveloping curve" at the highest observed concentrations and the variability in results

plotted below that curve. An evaluation of soil concentrations by distance and direction may provide information on the relative effects of tall stack versus low-level fugitive emissions from the smelter. It is possible, although yet to be demonstrated or adequately studied, that concentrations in some areas locally increase rather than decrease with greater distance as a result of tall stack impacts (which, except for stack fires or other accidental releases, should not affect areas close to the smelter significantly). The tall stack plume monitoring results in Lutrick (1971) are suggestive in this regard. A finding of "secondary maximum" impacts from tall stack emissions could change the prioritization of areas for future focus.

The regional-scale mapping of results also may help in demonstrating non-linear wind fields affecting the overall distribution of smelter contaminants. The simple assumption of linear wind fields and transport of contaminants according to the wind rose from a single location at the former smelter site is almost certainly too simple to be accurate; wind fields are expected to be more complicated and non-linear as a result of topographic relief and significant land-water boundaries affecting wind patterns. The pattern of soil contamination in the Footprint Study may suggest alternatives to simple linear wind fields over a mesoscale region (tens of miles) that will be helpful in planning future studies.

Additional statistical data evaluations will be performed, similar to the evaluations reported for previous King County studies (see PHSKC and Glass 2000 and 2001). Statistical summaries (e.g., frequency and percentile analyses) of the data by sampling zone will provide another means of summarizing spatial patterns in soil contamination across the entire study area. Other data evaluations will include assessments of the correlations among arsenic, lead, and tracer elements; analysis of depth profiles for soil contamination; comparisons of results for residential (disturbed) versus forested (undisturbed) land use types; and analyses of variability in contaminant concentrations within sampled properties and within zones (i.e., variability as a function of spatial scale). The effects on the magnitude and patterns of soil contamination of variables such as front yard versus back yard sampling location on residential properties, the age of houses on residential properties, slope conditions and elevations at all sampling locations, and possibly soil classification information will also be examined.

These data evaluations will provide information useful for the design of more detailed Remedial Investigation studies, as well as for continuing private citizen and local government activities to address contamination. The results of spatial pattern analyses of the Footprint Study results will be used to focus the study areas for the next TPCHD investigation under the current Ecology grant: sampling at Child Use Areas (e.g., schools, parks, playgrounds, and daycare centers) where children's potential soil exposures may be of concern.

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